MAINTENANCE OF SOIL ORGANIC MATTER: II. LOSSES OF CARBON AND NITROGEN FROM YOUNG AND MATURE PLANT MATERIALS DURING DECOMPOSITION IN SOIL

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Received for publication October 28, 1949

It is well known that when young succulent plant materials are incorporated into a soil they decompose rapidly and release a considerable portion of their nitrogen within a few days. In contrast, when mature woody materials are added to a soil they decompose more slowly and commonly retard crop growth unless supplemental nitrogen is applied. These facts have led many to believe that green manure carbon is so readily lost from soil that its addition, although of marked immediate benefit, is of little value in the maintenance of soil organic matter. In the previous paper (2) of the present series data were presented which show that green manure carbon is often held almost as tenaciously as is the carbon from brown manures. A year after incorporation of green oats into soil or sand-colloid mixtures an average of 34 per cent of the carbon remained; where wheat straw plus urea to give the same carbon-nitrogen ratio was added, 38 per cent of the carbon remained. The corresponding figures for the carbon of green soybean plants and corn stover plus urea were 28 and 38 per cent, respectively The present paper reports additional experimental work similar in many respects to that just mentioned and supplemental to it.

The primary purposes of the work reported here were (*a*) to obtain further direct comparisons of the stability, or persistence, of the carbon of green manures with that of mature materials when used as humus[2] sources, and (*b*) to determine to what extent nitrogen additions made to crop residues of wide carbon-nitrogen ratios tend to hold the carbon from these residues in the soil, as some workers (1, 5, 10, 12, 14) have reported or inferred. In addition, information was desired on the magnitude of the nitrogen gains through biological fixation, and on gaseous losses of nitrogen following addition of the various types of plant materials. Comparatively few data are available from long-time, carefully planned experiments that deal with these phases of humus formation.

EXPERIMENTAL METHODS

The methods used were, with minor exceptions, the same as given in the preceding paper (2). The composition of the organic materials used is given in table 1. They were added in sufficient quantities to supply 1 per cent carbon in all cases. All tests were made in beakers at 28°C. in the same Cecil clay loam subsoil (6–14 inches) used previously. This soil had a pH value of 4.9. The rate of application of calcium carbonate, where used, was 0.5 per cent. Urea was added in some instances together with the organic materials in amounts sufficient to make the carbon-nitrogen ratio 10. The soils were maintained at optimum moisture content and were not stirred during the experiment. Each analysis represented a soil from a different beaker rather than one of several samplings from the same beaker. At the end of the incubation period the soils were air-dried, ground in a ball mill, and analyzed for total carbon by the wet combustion method previously described (2). Nitrogen analyses were made by the Kjeldahl method using salicylic acid to include nitrates. All soil treatments were made in duplicate with single analyses for each sample.

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[2] The term "humus" is used to designate the well-decomposed portion of organic matter that has largely lost its original structure.

TABLE 1

Composition of organic materials

MATERIAL	CARBON	NITROGEN	C/N RATIO	LIGNIN
	per cent	*per cent*		*per cent*
Casein	47.9	15.6	3.1	—
Bluegrass	41.7	4.3	9.7	5.3
Oats	39.3	3.7	10.6	4.9
Millet, young	39.4	3.7	10.7	6.3
Soybeans	42.6	2.8	15.0	9.7
Lespedeza	44.3	2.5	18.1	14.2
Millet, intermediate	43.3	1.3	34.1	11.0
Oak leaves	46.3	0.7	64.3	21.9
Wheat straw	43.1	0.6	73.0	16.4
Corn stover	44.0	0.4	102.4	15.1
Cellulose	44.4	—	—	—

RESULTS

Humus formation from succulent green plant materials in acid Cecil clay loam

Table 2 shows the percentages of the added green manure carbon remaining in the soil after varying periods. Five young plant materials were used, three of which were especially succulent. Soybeans and lespedeza were slightly more fibrous than were bluegrass, oats, and millet but were typical green manure crops. When harvested, the soybeans were just starting to form pods and the lespedeza was in the blossom stage. A protein, casein, was included for comparison.

At the end of 1.5, 4, and 12 months of decomposition of the five plant materials in the soil the green manure carbon remaining averaged approximately 49, 40, and 36 per cent, respectively. The corresponding average values for the three most succulent materials were 48, 39, and 33 per cent. The values for casein, namely 25, 17, and 15 per cent, were lower but yet relatively high in view of the rate at which this protein is known to decompose apart from soil and the fact that it contains no lignin or lignin degradation products so important in humus formation. Neither these nor the earlier findings (2) indicate that green manure carbon disappears from a soil as quickly and completely as is generally believed.

Humus formation from mature plant materials in acid Cecil clay loam with and without fertilizer nitrogen

The results of studies similar to those reported in table 2 but with more woody plant materials are reported in table 3. The materials include millet, which was nearly mature, oak leaves, wheat straw, and corn stover. Cellulose in the form of ground filter paper was included for comparison. Since most of these materials were markedly deficient in nitrogen, sufficient fertilizer nitrogen was added to one set of samples to make the carbon-nitrogen ratio of added materials 10. This quantity of nitrogen was known to be much in excess of that required for a maximum rate of decomposition but was used in order to make the results comparable with those of some of the earlier workers. A nitrogen content of 1.2 to 1.5 per cent, which corresponds to a carbon-nitrogen ratio of about 28 to 35, is adequate (7) for a near-maximum rate of humification of crop residues. By use of urea as the nitrogen source, toxic residues were avoided and likewise any danger from excess nitrogen. Urea quickly goes to ammonia, which is readily used by microorganisms, or if formed in excessive amounts, some of it may escape as gas, especially in a limed soil.

TABLE 2

Organic carbon retention in unlimed Cecil clay loam following addition of 1 per cent carbon in the form of succulent green manures or protein

TREATMENT	C/N RATIO OF ADDED MATERIALS	CARBON PRESENT AFTER					
		1.5 months		4 months		12 months	
		Total C	Added C*	Total C	Added C*	Total C	Added C*
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
None		.427		.424		.403	
Casein	3.1	.677	25.0	.598	17.4	.556	15.2
Bluegrass clippings	9.7	.909	48.2	.819	39.5	.745	34.2
Oats	10.6	.900	47.3	.801	37.7	.732	32.9
Millet	10.7	.913	48.6	.826	40.2	.732	32.9
Soybeans	15.0	.895	46.8	.820	39.6	.779	37.6
Lespedeza	18.1	.986	55.9	.867	44.3	.812	40.9

* Portion of added organic carbon remaining. The difference required for significance between these treatment means is 3.7 at the 5 per cent level and 5.0 at the 1 per cent level.

In considering the data in table 3 and in one of the later tables (table 5), one should bear in mind that the figures show the percentages of the added carbon remaining after various incubation periods. It is not to be inferred that this carbon is all humus carbon. As pointed out in the previous paper, the methods for determining humus carbon are so unsatisfactory that it seemed best to determine total residual carbon only. In many cases, such as where a green manure crop has been allowed to decompose for 6 months or longer under optimum conditions, it is safe to assume that virtually all of the residual carbon is well humified. Likewise, more fibrous materials, such as straw, should be rather thoroughly humified after a year if adequate combined nitrogen to permit maximum biological action was supplied. Without the extra nitrogen, however, the crop residue may still be present in only a partly decomposed state.

Table 3 shows that the percentage of the carbon added as millet, wheat straw, and corn stover that remained after 1.5, 4, and 12 months averaged 68, 59, and 47, respectively, where no urea was supplied; where an abundance of supplemental nitrogen was added the corresponding figures were 48, 42, and 38. If oak leaves and cellulose, which are not typical of crop residues, are included the average values for the three periods in the absence of nitrogen are 75, 64, and 54; where urea was present the averages are 53, 45, and 40. These data show that addition of fertilizer nitrogen to carbonaceous crop residues incorporated into the soil is not necessary to hold the maximum amount of carbon. If nitrogen is added, the decay processes are accelerated, as has frequently been shown, and humus formation is favored. The results show that where nitrogen is deficient there is no excessive loss of carbon dioxide; on the contrary, the plant materials tend to remain in a partly decomposed state. From the practical standpoint, there are many good reasons for applying supplemental nitrogen when materials of wide carbon-nitrogen ratio are turned under, especially if a crop is to be planted soon, but to add fertilizer nitrogen for the sole purpose of holding the added carbon would appear from these data to be a practice without scientific basis.

TABLE 3

Organic carbon retention in unlimed Cecil clay loam following addition of 1 per cent carbon in the form of mature (or nearly mature) plant materials and with or without supplemental nitrogen

TREATMENT	C/N RATIO OF ADDED MATERIALS	CARBON PRESENT AFTER					
		1.5 months		4 months		12 months	
		Total C	Added C*	Total C	Added C*	Total C	Added C*
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
None		0.427		0.424		0.403	
Millet, heads formed	34.1	0.977	55.0	0.901	47.7	0.798	39.5
Millet + urea	10.0	0.916	48.9	0.858	43.4	0.790	38.7
Oak leaves	64.3	1.206	77.9	1.117	69.3	0.948	54.5
Oak leaves + urea	10.0	1.082	65.5	1.011	58.7	0.917	51.4
Wheat straw	73.0	1.193	76.6	1.062	63.8	0.920	51.7
Wheat straw + urea	10.0	0.931	50.4	0.847	42.3	0.783	38.0
Corn stover	102.4	1.157	73.0	1.064	64.0	0.890	48.7
Corn stover + urea	10.0	0.875	44.8	0.827	40.3	0.777	37.4
Cellulose	—	1.346	91.9	1.157	73.3	1.178	77.5
Cellulose + urea	10.0	0.990	56.3	0.800	37.6	0.726	32.3

* Portion of added organic carbon remaining. The difference required for significance between these treatment means is 4.8 at the 5 per cent level and 6.4 at the 1 per cent level.

In the presence of urea the percentages of the added carbon remaining after a year were for oak leaves 51, millet 39, wheat straw 38, corn stover 37, and cellulose 32. Most of the carbon loss occurred during the first 6 weeks but after the readily decomposable materials had been utilized, humification proceeded very slowly. The average value of 38 for the three typical carbonaceous plant materials is only slightly higher than the value of 36 reported in table 2 for the five succulent materials (or 33 for the three very young green crops). These values agree closely with those presented in the previous paper of this series. Per unit of carbon added, most succulent green manures seem to furnish carbon that is about 80 to 90 per cent as permanent in the soil as is mature plant carbon. In both cases a considerable, but unknown, portion of the added plant carbon is transformed into microbial carbon. When it is in this form, its resistance to decay would, of course, be largely independent of the nature of the material from which it was derived.

TABLE 4

Organic carbon retention in limed Cecil clay loam following addition of 1 per cent carbon in the form of succulent green manures or protein

TREATMENT	C/N RATIO OF ADDED MATERIALS	CARBON PRESENT AFTER					
		1.5 months		4 months		12 months	
		Total C	Added C*	Total C	Added C*	Total C	Added C*
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
None		.383		.373		.355	
Casein	3.1	.655	27.2	.572	19.9	.551	19.6
Bluegrass clippings	9.7	.789	40.6	.765	39.2	.647	29.2
Oats	10.6	.850	46.7	.785	41.2	.672	31.7
Millet, young	10.7	.801	41.8	.776	40.3	.691	33.6
Soybeans	15.0	.825	44.2	.801	42.8	.690	33.5
Lespedeza	18.1	.868	48.5	.851	47.8	.727	37.2

* Portion of added organic carbon remaining. The difference required for significance between these treatment means is 3.7 at the 5 per cent level and 5.0 at the 1 per cent level.

Humus formation from succulent green plant materials in limed Cecil clay loam

It is a well-known fact that additions of lime to an acid soil usually accelerate the decomposition of added organic materials. Less is known about the effect of lime on the percentage of carbon remaining after several months. The studies with Mohave clay loam, reported in the previous paper of this series, showed that lime usually somewhat increased the loss of carbon at all three incubation periods. Figures for the retention of the carbon of several green crops, allowed to decompose in limed Cecil soil, are reported in table 4. These results are directly comparable with those in table 2 for the unlimed Cecil soil.

The rate of carbon dioxide evolution from the various materials in Cecil soil was, in most instances, increased, but not markedly, by additions of calcium carbonate. At the end of a year the average percentage of the carbon retained, exclusive of that in casein, was about 36 in the absence and 33 in the presence of calcium carbonate. Obviously green manure carbon is a good source of humus carbon regardless of the base content of the soil.

Humus formation from mature plant materials in limed Cecil clay loam with and without fertilizer nitrogen

The effect of lime on the humification of mature plant materials can be seen by comparing table 5 with table 3.

Lime, in most cases, significantly increased the carbon loss, the effect being more marked with increase in length of the incubation period. After a year the approximate average carbon retention figures for the five carbon sources that decomposed under conditions of adequate nitrogen were 38 in the acid soil and 33 in the presence of lime. The effect of lime in accelerating the humification process was, therefore, similar for succulent and mature plant materials but slightly more marked for the latter.

TABLE 5

Organic carbon retention in limed Cecil clay loam following addition of 1 per cent carbon in the form of mature (or nearly mature) plant materials and with or without supplemental nitrogen

TREATMENT	C/N RATIO OF ADDED MATERIALS	CARBON PRESENT AFTER					
		1.5 months		4 months		12 months	
		Total C	Added C*	Total C	Added C*	Total C	Added C*
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
None		0.383		0.373		0.355	
Millet, head formed	34.1	0.902	51.9	0.834	46.1	0.690	33.5
Millet + urea	10.0	0.873	49.0	0.803	43.0	0.692	33.7
Oak leaves	64.3	1.038	65.5	0.971	59.8	0.746	39.1
Oak leaves + urea	10.0	0.957	57.4	0.938	56.5	0.773	41.8
Wheat straw	73.0	1.078	69.5	0.986	61.3	0.752	39.7
Wheat straw + urea	10.0	0.853	47.0	0.816	44.3	0.710	35.5
Corn stover	102.4	1.054	67.1	0.946	57.3	0.730	37.5
Corn stover + urea	10.0	0.849	46.6	0.760	38.7	0.656	30.1
Cellulose	—	1.226	84.3	1.170	79.7	1.095	74.0
Cellulose + urea	10.0	0.981	59.8	0.794	42.1	0.618	26.3

* Portion of added organic carbon remaining. The difference required for significance between these treatments means is 4.8 at the 5 per cent level and 6.4 at the 1 per cent level.

Gaseous losses of nitrogen during decomposition of materials of varying carbon-nitrogen ratios

Although the experiments reported were planned primarily to study carbon losses during humus formation, results were also obtained in some cases on the nitrogen changes. With respect to nitrogen, information was sought on (*a*) whether addition of plant materials of wide carbon-nitrogen ratios results in appreciable biological nitrogen fixation and (*b*) at what carbon-nitrogen ratio loss of gaseous forms of nitrogen becomes appreciable. To answer these questions the limed and unlimed soils, from the 4-month incubation period, that had received the various carbon sources without supplemental urea were analyzed for total nitrogen. The results are given in table 6.

No significant gains in nitrogen occurred with any of the carbon sources added in either the acid or the limed Cecil soil. These negative results were probably due in part to the absence of Azotobacter and possibly other species of nitrogen-fixing organisms commonly found in soils of near neutral or alkaline reaction. It is also possible that some nitrogen fixation may have occurred but was either not in sufficient quantity to be detected by the Kjeldahl method or was offset by losses of ammonia or free nitrogen gas.

TABLE 6

Nitrogen losses after 4 months from Cecil soil receiving various sources of organic matter without supplemental nitrogen

All results are based on 100 gm. of soil

TREATMENT	C/N RATIO OF ADDED MATERIALS	NITROGEN ADDED IN CARBON SOURCES	UNLIMED			LIMED		
			Nitrogen found*	Nitrogen lost	Added N lost	Nitrogen found*	Nitrogen lost	Added N lost
		mgm.	*mgm.*	*mgm.*	*per cent*	*mgm.*	*mgm.*	*per cent*
Soil only			37.5			35.6		
Casein	3.1	326.2	146.6	217.1	66.6	134.8	227.0	69.6
Bluegrass	9.7	103.6	124.7	16.4	15.8	108.6	30.6	29.5
Oats	10.6	94.8	111.1	21.2	22.4	100.8	29.6	31.2
Millet, young	10.7	93.2	111.7	19.0	20.4	104.1	24.7	26.5
Soybeans	15.0	66.5	96.3	7.7	11.6	85.5	16.6	25.0
Lespedeza	18.1	55.4	89.8	3.1	5.6	87.5	3.5	6.3
Millet, intermediate	34.1	29.4	64.8	2.1	7.1	64.7	0.3	1.0
Oak leaves	64.3	15.6	51.7	1.4	9.0	51.7	+0.5	+3.2
Wheat straw	73.0	13.8	49.7	1.6	11.6	47.5	1.9	17.4
Corn stover	102.4	9.8	47.1	0.2	2.0	46.0	+0.6	+6.1
Cellulose	—	0	37.0	0.5	—	36.8	+1.2	—

* Least significant difference between treatment means = 4.4 at the 5 per cent level and 5.9 at 1 per cent level.

Table 6 shows no significant loss of gaseous forms of nitrogen from the decomposing plant materials where the carbon-nitrogen ratio was 18 or wider. As the ratio narrowed from 15 to 3 the losses became increasingly larger. Bluegrass, oats, and millet, with carbon-nitrogen ratios near 10, lost about 29 per cent of their nitrogen in the limed soil and 20 per cent in the acid soil. About two thirds of the casein nitrogen was volatilized. These gaseous losses presumably occurred mostly as ammonia, although there is a possibility of some loss as free nitrogen following oxidation to nitrates. In view of the fact that plant materials having carbon-nitrogen ratios of about 28 to 35 have just enough nitrogen to permit normal decay during the first few months, gaseous losses would not be expected unless the ratio were considerably narrower than this. Just how narrow it would have to be for losses to occur would depend upon a number of factors, especially the quantity that accumulated as nitrate and the quantity held as ammonia in the exchange complex. In fact, under practical conditions, where rates of addition of plant materials to soil are usually considerably lower than those used here, losses of ammonia may be negligible because of absorption by soil colloids.

DISCUSSION

In studies in a sandy soil Engel (4) found that of the carbon added as beet leaves, lupine tops, and lupine roots 29, 19, and 36 per cent, respectively, remained after 4 months. Since all of these materials had carbon-nitrogen ratios between 11 and 15, composition was the main factor determining carbon retention.

Extensive organic matter studies were made by Salter (10) in a silt loam to which several sources of carbon and varying quantities of ammonium nitrate were added. Regardless of the source of carbon, the quantity present at the end of a year fell within a rather narrow range when the materials were adjusted to a common carbon-nitrogen ratio. Salter concluded that a ratio wider than 10 favors the loss of organic carbon from soil, whereas a narrower ratio leads to the saving of carbon. These findings are at variance with those obtained by others, including the work discussed in this and the preceding paper of the series. In evaluating Salter's results the following facts or suggestions should be considered: (*a*) The soil used contained, or formed, so much available nitrogen that even where the most carbonaceous materials were added without supplemental nitrogen, 30 to 60 pounds of nitrate nitrogen per acre was present after 1 month, and 80 to 240 pounds after 6 months. (*b*) Since all materials decomposed under conditions of adequate nitrogen, it seems probable that the higher rates of ammonium nitrate, which ranged up to 5.7 tons per acre, may have caused considerable retardation of biological activities.

Millar, Smith, and Brown (5) concluded from plant decomposition experiments that materials high in nitrogen left more carbon in the soil than did those low in nitrogen. After 190 days the carbon retention values for seven materials, having carbon-nitrogen ratios of 32 to 77, averaged 20; five other materials with ratios less than 23, averaged 32. Since the rate of release of nitrogen from the soil organic matter was high, supplemental additions would probably not have increased carbon retention; plant composition was obviously the important factor.

In greenhouse experiments, Turk and Millar (14) observed greater losses of carbon where materials of low nitrogen content were added than where more nitrogenous materials were used. At the end of the experiment 25 per cent of the carbon of straw and 34 per cent of that of sweet clover remained. Although the value of nitrogen in holding carbon is emphasized, it would seem that the experiments serve more to demonstrate the importance of plant composition. A treatment consisting of straw plus nitrogen to make the carbon-nitrogen ratio comparable to that of sweet clover was not included.

In experiments conducted in cylinders in the open, Siegel (11) added various organic materials and supplemental nitrogen in some instances, grew a crop, and determined the percentage of added carbon (exclusive of plant roots) remaining after 1 and 3 years. These results, given in part in table 7, show that the carbon of green manures was usually retained at least as tenaciously as that of straw and that addition of large amounts of nitrogen to straw had little or no effect on the quantity of added carbon that was held.

In a recent paper, Peevy and Norman (6) reported that the composition of plant materials, especially the content of lignin, materially influences the quantity and properties of the decomposed residues. Dextrose and cellulose disappeared more quickly than any other materials studied, even though adequate supplemental nitrogen was added. Furthermore, nitrogen had a negligible effect in holding the carbon of soybean stalks having a carbon-nitrogen ratio of 62.

The results reported in tables 2 to 5 are in close agreement with most of the experiments mentioned, as well as with other work (3, 13, 15), in showing that carbon retention in a normal soil is determined primarily by the chemical nature of the plant materials added. Even a unit of carbon in the form of a succulent green crop may form just as much humus as a similar amount of carbon added as a mature plant residue. This was shown very clearly in greenhouse experiments (8, 9) conducted at this laboratory. Also, in the present experiments plant composition was more important than age. There was little difference, for instance, between the behavior of succulent soybeans and lespedeza, on the one hand, and of mature wheat straw and corn stalks supplemented with urea, on the other. Other more succulent materials were somewhat less tenaciously held, but doubtless this was due more to lower lignin content than to age.

TABLE 7

Percentage of added carbon retained by a soil-sand mixture at different nitrogen levels

MATERIAL ADDED*	CARBON-NITROGEN RATIO	PERCENTAGE OF ADDED CARBON RETAINED AFTER	
		1 year	3 years
Straw	166.8	30.7	11.9
Straw	20.0	31.3	10.1
Straw	10.0	25.7	12.0
Clover	14.9	36.9	16.0
Plant mixture	13.5	32.1	17.0
Mustard	16.2	28.1	13.1
Mustard	10.0	23.9	10.6

* Materials equivalent to 0.7 per cent C were added.

The belief that nitrogen is required to hold carbon in a soil, a view held by some but certainly not all workers, is also shown to be largely without foundation, although the reverse of this statement is true, as shown in table 6. Addition of available nitrogen to nitrogen-deficient materials commonly greatly accelerates the humification process and loss of carbon during the first few weeks. There is little to indicate, however, that in absence of adequate nitrogen, the decay process, which continues slowly, leads to an excessive loss of carbon. As humus formation proceeds, most of the readily available energy sources are destroyed, whereas lignin degradation products, hemicellulose, and protein tend to accumulate either as residual materials or as products of microbial synthesis. Unless the supply of nitrogen is extremely deficient, its absence will have little effect on the nature of these transformations, although, as already stated, the rate of change will be retarded. Such extremely nitrogen-deficient conditions ordinarily occur only in an artificial medium. In a normal soil, the usual oxidation of soil organic matter with the consequent release of available nitrogen will at least eventually furnish enough supplemental nitrogen (if any is needed) for approximately maximum humus formation. Supplemental nitrogen may be, and usually is, needed to meet the needs of the crop but not to hold carbon. It should also be remembered that nitrogen additions to cropped soils commonly increase (9) soil carbon by increasing crop growth and crop residues, but there is no sound evidence that such additions exert a holding action on carbon already present in the soil or added as outside sources.

SUMMARY

Laboratory experiments are reported on humus formation, in both limed and unlimed Cecil clay loam, from plant materials of varying degrees of maturity and nitrogen content allowed to decompose for a year.

The percentages of the added carbon left in the soil after an extended period of decomposition is determined primarily by the composition of the materials added and not by their carbon-nitrogen ratios.

Contrary to popular belief, the carbon of succulent green manure crops was retained by the soil to almost as great a degree as was that of mature plant materials.

The findings do not substantiate the claim that supplemental additions of nitrogen to nitrogen-deficient crop residues are necessary to hold carbon during the process of humus formation in soil. The main effect of nitrogen additions under such conditions is to accelerate the process of humus formation and to feed the crop, if present. Where nitrogen is deficient, carbonaceous materials tend to remain in a partly decomposed condition.

It is pointed out that nitrogen additions to a cropped soil often result in a higher level of organic matter because of the resulting larger crop residues, but this effect of nitrogen falls outside the range of the present studies.

Where materials having carbon-nitrogen ratios of 18 to 102 were added to soil, no significant loss of gaseous forms of nitrogen occurred; where the ratios were 3 to 15, marked nitrogen losses occurred that increased as the nitrogen content increased. This emphasizes the importance of carbon in holding nitrogen.

Addition of calcium carbonate to an acid Cecil soil usually increased somewhat the rate of decomposition of the added carbon sources and decreased the quantity of carbon retained by the soil at the end of a year.

No significant nitrogen fixation occurred in either the limed or the unlimed

soil as a result of addition of plant materials. This may have been due to lack of Azotobacter in the original acid Cecil soil.

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